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state that the attached documents are a true and complete translation to the best of my knowledge of Japanese Patent Application No. 196251/1999

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[Title of Invention] Optical Amplifier and Optical Amplifier Control Method

[Claims]

[Claim 1] An optical amplifier, comprising:

an optical amplification section for amplifying signal light with pumping light;

pumping means for supplying pumping light to said optical amplification section;

output controlling means for performing control such that power outputted from said optical amplification section constitutes a predetermined target value;

a variable loss-gradient device, whereby the loss in a prescribed wavelength within the wavelength band of a signal light is approximately constant, and the gradient of loss related to a wavelength in said wavelength band is variable; and

loss gradient controlling means for controlling the gradient of said loss, and compensating the gradient of gain in relation to a wavelength of said optical amplification section.

[Claim 2] The optical amplifier according to Claim 1, further comprising a gain equalizer for equalizing inherent wavelength-dependency of the gain of said optical amplification section.

[Claim 3] The optical amplifier according to Claim 1, wherein said loss gradient controlling means controls the gradient of said loss based on the power inputted to said optical amplification section.

[Claim 4] The optical amplifier according to Claim 1, wherein said loss gradient controlling means controls the gradient of said loss based on the gain of optical amplification in said optical amplification section.

[Claim 5] The optical amplifier according to Claim 1, wherein said loss gradient controlling means controls the gradient of said loss based on the power deviation of respective wavelengths outputted from said optical amplification section.

[Claim 6] The optical amplifier according to Claim 1, wherein said variable loss-gradient device comprises:

a main optical path for guiding signal light;

a first sub optical path, which is optically coupled to said main optical path via a first optical coupler and a second optical coupler, respectively, and which constitutes a first Mach-Zehnder interferometer together with said main optical path and said first and second optical couplers, and;

a second sub optical path, which is optically coupled to said main optical path via a third optical coupler and a fourth optical coupler,

respectively, and which constitutes a second Mach-Zehnder interferometer together with said main optical path and said third and fourth optical couplers, and;

wherein first temperature adjusting means for adjusting the temperature of either one or both of said main optical path and said first sub optical path between said first optical coupler and said second optical coupler; and

second temperature adjusting means for adjusting the temperature of either one or both of said main optical path and said second sub optical path between said third optical coupler and said fourth optical coupler, and

said loss gradient controlling means controls the gradient of said loss by controlling said first and said second temperature adjusting means of said variable loss-gradient device.

[Claim 7] The optical amplifier according to Claim 1, wherein said variable loss-gradient device is disposed in the output side of said optical amplification section.

[Claim 8] The optical amplifier according to Claim 1, wherein said optical amplification section is divided into a plurality of stages, and said variable loss-gradient device is disposed between one stage and another stage of said optical amplification section.

[Claim 9] A method of controlling an optical amplifier, which comprises an optical amplification section for amplifying signal light with pumping light; and pumping means for supplying pumping light to said optical amplification section, said optical amplifier control method comprising:

performing control such that the power outputted from said optical amplification section constitutes a predetermined target value; and

utilizing a variable loss-gradient device, whereby the loss in a prescribed wavelength within the wavelength band of a signal light is approximately constant, and the gradient of loss in relation to a wavelength in said wavelength band is variable, for controlling the gradient of said loss, and compensating the gradient of gain related to a wavelength of said optical amplification section.

[Claim 10] The optical amplifier control method according to Claim 9, whereby an inherent wavelength-dependency of the gain of said optical amplification section is equalized using a gain equalizer.

[Claim 11] The optical amplifier control method according to Claim 9, whereby the gradient of said loss is controlled on the basis of the power inputted to said optical amplification section.

[Claim 12] The optical amplifier control method

according to Claim 9, whereby the gradient of said loss is controlled on the basis of the gain of optical amplification in said optical amplification section.

[Claim 13] The optical amplifier control method according to Claim 9, whereby the gradient of said loss is controlled on the basis of the power deviation of respective wavelengths outputted from said optical amplification section.

[Claim 14] The optical amplifier control method according to Claim 9, whereby said variable loss-gradient device comprises:

a main optical path for guiding signal light;

a first sub optical path, which is optically coupled to said main optical path via a first optical coupler and a second optical coupler, respectively, and which constitutes a first Mach-Zehnder interferometer together with said main optical path and said first and second optical couplers;

a second sub optical path, which is optically coupled to said main optical path via a third optical coupler and a fourth optical coupler, respectively, and which constitutes a second Mach-Zehnder interferometer together with said main optical path and said third and fourth optical couplers;

first temperature adjusting means for

adjusting the temperature of either one or both of said main optical path and said first sub optical path between said first optical coupler and said second optical coupler; and

second temperature adjusting means for adjusting the temperature of either one or both of said main optical path and said second sub optical path between said third optical coupler and said fourth optical coupler, and wherein

the gradient of loss of said variable loss-gradient device is controlled by controlling said first and said second temperature adjusting means of said variable loss-gradient device.

[Claim 15] The optical amplifier control method according to Claim 9, whereby said variable loss-gradient device is disposed in the output side of said optical amplification section.

[Claim 16] The optical amplifier control method according to Claim 9, whereby said optical amplification section is divided into a plurality of stages, and said variable loss-gradient device is disposed between one stage and another stage of said optical amplification section.

[Detailed Explanation of the Invention]

[0001]

[Technical Field of the Invention]

The present invention is related to an optical amplifier, which collectively amplifies signal light of multiple wavelengths, and a control method for this optical amplifier.

[0002]

[Prior Art]

An optical amplifier comprises a signal light-amplifying optical amplification section, which has been doped with a fluorescent material that can be pumped by pumping light, and pumping means for supplying pumping light to this optical amplification section, and is disposed in a relay station in an optical transmission system. It is particularly important that an optical amplifier, which is used in a wavelength-division multiplexed transmission system for transmitting a plurality of signal light components of different wavelengths, collectively amplifies the respective signal light components of the different wavelengths at mutually equal gains, and outputs the respective powers of the plurality of signal light components of different wavelengths as a fixed target value.

[0003] For example, reference 1, K. Inoue, et al., "Tunable Gain Equalization Using a Mach-Zehnder Optical Fiber in Multistage Fiber Amplifiers", IEEE Photonics Technology Letters, Vol. 3, No. 8, pp. 718 - 720 (1991)

is disclosed a technique of flattening the gain of an optical amplifier by an optical fiber using a Mach-Zehnder interferometer. Reference 2, S. Kinoshita, et al., "Large Capacity WDM Transmission Based on Wideband Erbium-Doped Fiber Amplifiers", OSA TOPS, Vol. 25, pp. 258 - 261 (1998) is disclosed a technique in which an optical attenuator with a variable attenuation factor is inserted between the input-side optical amplification section and the output-side optical amplification section of an optical amplifier so as to maintain constant power of signal light input to the output-side optical amplification section even when the power of signal light input to the input-side optical amplification section varies, thereby maintaining the power of signal light output from the optical amplifier at a predetermined target value and simultaneously maintaining constant gain deviation of the entire optical amplifier.

[0004]

[Objects To Be Solved by the Invention]

In the technique described in reference 1, however, for example, to keep the power of signal light output from the optical amplifier at a predetermined target value when the loss in the input-side transmission line of the optical amplifier varies due to some reason, and the power of signal light input to

the optical amplifier varies, the gain of optical amplification of signal light in the optical amplifier must be changed. Then, when the gain is changed, the wavelength dependence of the gain, i.e. the gain gradient, fluctuates, and as a result of this, the gain flatness of the optical amplifier is lost, and the respective powers of the plurality of signal light components of different wavelengths outputted from the optical amplifier exhibit deviation.

[0005] Further, in the technology disclosed in the above-mentioned literature 2, when an attempt is made to use an optical attenuator to maintain the power of the signal light inputted to the output-side of the optical amplification section at a fixed target value, and the power of the signal light inputted to the input-side of the optical amplification section is sufficiently large, the optical attenuator greatly attenuates the signal power, with the result that pumping efficiency becomes poor and the noise factor deteriorates.

[0006] The present invention has been made to solve the above problems, and has as its object to provide an optical amplifier and optical amplifier control method capable of maintaining the output signal light power and gain flatness without degrading the noise factor even when the input signal light power varies.

[0007]

[Means for Solving The Problems]

An optical amplifier related to the present invention is characterized in that it comprises (1) an optical amplification section for amplifying signal light with pumping light; (2) pumping means for supplying pumping light to the optical amplification section; (3) output controlling means for performing control such that power outputted from the optical amplification section constitutes a predetermined target value; (4) a variable loss-gradient device, whereby loss in a prescribed wavelength within the wavelength band of the signal light is approximately constant, and the gradient of the loss relative to a wavelength in the wavelength band is variable; and (5) loss-gradient controlling means for controlling the gradient of loss, and for compensating the gradient of gain relative to a wavelength of the optical amplification section.

[0008] An optical amplifier control method related to the present invention is a control method for an optical amplifier, which comprises an optical amplification section for amplifying signal light with pumping light, and pumping means for supplying pumping light to the optical amplification section, [this control method] being characterized in that control is

performed such that power outputted from the optical amplification section constitutes a predetermined target value, and, in addition, a variable loss-gradient device, whereby loss in a prescribed wavelength within the wavelength band of the signal light is approximately constant, and the gradient of the loss relative to a wavelength in the wavelength band is variable, is utilized to control the gradient of loss, and to compensate the gradient of gain relative to a wavelength of the optical amplification section.

[0009] According to the optical amplifier or optical amplifier control method of the present invention, even when the input signal light power to the optical amplifier varies, the output signal light power from the optical amplifier can be maintained at a predetermined target value.

Further, even if fluctuation of the inputted signal light power gives rise to gradients of optical amplification section gain, it is possible to maintain the gain flatness of the optical amplifier as a whole by adjusting the gradient of loss of the variable loss-gradient device. In addition, since the loss of the variable loss-gradient device is approximately constant in a prescribed wavelength within the wavelength band of the signal light, there is no deterioration of the

noise factor.

[0010] Further, an optical amplifier related to the present invention is characterized in that it further comprises a gain equalizer for equalizing the inherent wavelength-dependency of the gain of the optical amplification section. An optical amplifier control method related to the present invention is characterized in that it uses a gain equalizer to equalize the inherent wavelength-dependency of the gain of the optical amplification section. In this case, since the gain gradient of the optical amplification section is compensated and the inherent wavelength-dependency of the gain of the optical amplification section is equalized by the variable loss-gradient device, the gain flatness of the optical amplifier as a whole is outstanding.

[0011] Further, in an optical amplifier related to the present invention, loss-gradient controlling means can either be characterized such that the gradient of loss is controlled on the basis of the power inputted to the optical amplification section; or characterized such that the gradient of loss is controlled on the basis of the gain of optical amplification in the optical amplification section; or characterized such that the gradient of loss is controlled on the basis of the deviation of power of the respective wavelengths

outputted from the optical amplification section. Even an optical amplifier control method related to the present invention can either be characterized such that the gradient of loss is controlled on the basis of the power inputted to the optical amplification section; or characterized such that the gradient of loss is controlled on the basis of the gain of optical amplification in the optical amplification section; or characterized such that the gradient of loss is controlled on the basis of the deviation of power of the respective wavelengths outputted from the optical amplification section. Any one of these cases is ideal for compensating the gain gradient of the optical amplification section and maintaining the gain flatness of the optical amplifier as a whole using the variable loss-gradient device.

[0012] Further, in each of an optical amplifier and optical amplifier control method related to the present invention, it is preferable that the variable loss-gradient device comprises (1) a main optical path for guiding signal light; (2) a first sub optical path, which is optically coupled to the main optical path via a first optical coupler and a second optical coupler, respectively, and which constitutes a first Mach-Zehnder interferometer together with the main optical path and the first and second optical couplers; (3) a

second sub optical path, which is optically coupled to the main optical path via a third optical coupler and a fourth optical coupler, respectively, and which constitutes a second Mach-Zehnder interferometer together with the main optical path and the third and fourth optical couplers; (4) first temperature adjusting means for adjusting the temperature of either one or both of the main optical path and the first sub optical path between the first optical coupler and the second optical coupler; and (5) second temperature adjusting means for adjusting the temperature of either one or both of the main optical path and the second sub optical path between the third optical coupler and the fourth optical coupler. Then, it is characterized such that the gradient of loss is controlled by controlling first and second temperature adjusting means of the variable loss-gradient device. This variable loss-gradient device is constituted such that the first and second Mach-Zehnder interferometers are cascaded, and the loss spectrum of this variable loss-gradient device as a whole is determined in accordance with the respective transmission spectrums of the first and second Mach-Zehnder interferometers, which are set by adjusting the temperature via first and second temperature adjusting means.

[0013] Further, in each of an optical amplifier and

optical amplifier control method related to the present invention, it is preferable that the variable loss-gradient device be disposed in the output side of the optical amplification section, and it is preferable that the optical amplification section be divided into a plurality of stages, and the variable loss-gradient device be disposed between [one] stage and [another] stage of the optical amplification section. The more toward the output side the variable loss-gradient device is installed, the less the noise factor deteriorates, and the more toward the input side the variable loss-gradient device is installed, the better the pumping efficiency.

[0014]

[Embodiments of the Invention]

The embodiments of the present invention will be explained in detail hereinbelow by referring to the attached figures. Furthermore, in the explanations of the figures, the same numerals will be assigned to like elements, and redundant explanations will be omitted.

[0015]

(First Embodiment)

Firstly, a first embodiment of an optical amplifier and optical amplifier control method related to the present invention will be explained. Fig. 1 is a simplified block diagram of an optical amplifier 100

related to the first embodiment. An optical amplifier 100 related to the first embodiment has an optical coupler 130, an input-side optical amplification section 111, a variable loss-gradient device 140, and output-side optical amplification section 112 connected in sequence from the optical input terminal 101 to the optical output terminal 102. Further, in addition, the optical amplifier 100 comprises a pumping light source 121 for supplying pumping light to the input-side optical amplification section 111, a pumping light source 122 for supplying pumping light to the output-side optical amplification section 112, and a control circuit 150 for controlling the loss spectrum of the variable loss-gradient device 140.

[0016] The optical coupler 130 demultiplexes a portion of the light that arrives from the optical input terminal 101 and outputs it toward the control circuit 150, and outputs the remaining portion [of the light] to the input-side optical amplification section 111. The input-side optical amplification section 111 is supplied with pumping light by the pumping light source 121, and signal light arriving from the optical coupler 130 is collectively amplified and outputted. The variable loss-gradient device 140 has a loss spectrum, wherein the loss in a prescribed wavelength within the wavelength band of the signal light is approximately

constant, and the gradient of loss relative to a wavelength in this wavelength band is variable. The output-side optical amplification section 112 is supplied with pumping light by a pumping light source 122, and signal light arriving from the variable loss-gradient device 140 is collectively amplified and outputted to the optical output terminal 102.

[0017] The control circuit 150 detects the power of signal light demultiplexed by the optical coupler 130. The control circuit 150 controls the power of optical pumping light to be output from the optical pumping light sources 121 and 122 on the basis of the power of input signal light such that the power of output signal light obtains a predetermined target value. The control circuit 150 also controls the loss-gradient of the variable loss-gradient device 140 on the basis of the power of input signal light.

[0018] Fig. 2 is an explanatory view of the input-side optical amplification section 111 and optical pumping light source 121. The input-side optical amplification section 111 includes an amplification optical fiber 113, optical coupler 114, and optical isolators 115 and 116. The optical coupler 114 sends optical pumping light output from the optical pumping light source 121 to the amplification optical fiber 113 and also passes signal light output from the amplification optical fiber 113.

The optical isolators 115 and 116 pass light in the forward direction but do not pass light in the reverse direction.

[0019] The amplification optical fiber 113 is an optical waveguide for optically amplifying signal light, doped with a fluorescent material that can be excited by optical pumping light output from the optical pumping light source 121. The fluorescent material to be doped is preferably a rare earth element and, more preferably, Er. Er is preferably doped because signal light in a 1.55-□m band can be optically amplified. At this time, the wavelength of optical pumping light to be output from the optical pumping light source 121 and supplied to the amplification optical fiber 113 is preferably 1.48 □m or 0.98 □m. The output-side optical amplification section 112 and optical pumping light source 122 have the same arrangement as described above.

[0020] A preferred example of the variable loss-gradient device 140 will be described next. Fig. 3 is an explanatory view of the variable loss-gradient device 140. This variable loss-gradient device 140 is a planar lightwave circuit formed on a substrate 10 made of, e.g., quartz, and comprises a main optical path 20, first sub optical path 21, second sub optical path 22, heater 51 serving as a first temperature adjustment means, and heater 53 serving as a second

temperature adjustment means.

[0021] The main optical path 20 guides light incident on the optical input terminal 11 at one end face of a substrate 10 to the optical output terminal 12 at the other end face of the substrate 10 sequentially via a first coupler 31, second coupler 32, third coupler 33, and fourth coupler 34, and emits the light from the optical output terminal 12. The main optical path 20 and a first sub optical path 21 are optically coupled together via the first optical coupler 31 and the second optical coupler 32, respectively. Then, the main optical path 20, first sub optical path 21, first optical coupler 31 and second optical coupler 32 constitute a first Mach-Zehnder interferometer 41. The main optical path 20 and a second sub optical path 22 are optically coupled together via the third optical coupler 33 and the fourth optical coupler 34, respectively. Then, the main optical path 20, second sub optical path 22, third optical coupler 33 and fourth optical coupler 34 constitute a second Mach-Zehnder interferometer 42.

[0022] A heater 51 is disposed on the main optical path 20 between the first optical coupler 31 and second optical coupler 33. This heater 51 adjusts the temperature of the main optical path 20 to adjust the optical path length difference between the main optical

path 20 and the first sub optical path 21 in the first Mach-Zehnder interference circuit 41, thereby adjusting the transmission characteristic of the first Mach-Zehnder interference circuit 41. The heater 53 is formed on the fifth region E of the main optical path 20. This heater 53 adjusts the temperature of the main optical path 20 to adjust the optical path length difference between the main optical path 20 and the second sub optical path 22 in the second Mach-Zehnder interference circuit 42, thereby adjusting the transmission characteristic of the second Mach-Zehnder interference circuit 42. The heaters 51 and 53 are controlled by the control circuit 150.

[0023] Furthermore, a heater can be disposed on the first sub optical path 21 between the first optical coupler 31 and the second optical coupler **33[??32]**, and a heater can be disposed on the main optical path 20 between the third optical coupler 33 and the fourth optical coupler 34. Further, Peltier elements can be provided in place of heaters.

[0024] In the variable loss-gradient device 140, the loss spectrum for light input to the optical input terminal 11 and output from the optical output terminal 12 through the main optical path 20 is determined by the transmittance characteristic of the first Mach-Zehnder interferometer 41 based on optical

coupling between the main optical path 20 and the first sub optical path 21 by the optical couplers 31 and 32 and the transmittance characteristic of the second Mach-Zehnder interferometer 42 based on optical coupling between the main optical path 20 and the second sub optical path 22 by the optical couplers 33 and 34. This variable loss-gradient device 140 is preferable because it is integrated on the substrate 10 and has a compact structure and also because of its small insertion loss.

[0025] Operation of the optical amplifier 100 according to the first embodiment will be described next, and an optical amplifier control method according to the first embodiment will be described. Fig. 4 is a view for explaining operation of the optical amplifier 100 according to the first embodiment. As for the loss spectrum (Fig. 4A) of the variable loss-gradient device 140, the loss is almost constant at the predetermined wavelength in the wavelength band of signal light, and the loss gradient with respect to wavelengths is variable in the wavelength band. The loss gradient is controlled by the control circuit 150 which monitors the input signal light power.

[0026] When the input signal light power is a predetermined value, and the gain of the amplification of signal light in the input-side optical amplification

section 111 and output-side optical amplification section 112 is approximately constant without being wavelength-dependent (Fig. 4 (b)), and when the input signal light power relative thereto is smaller than a predetermined value, the gain of signal light amplification in the input-side optical amplification section 111 and output-side optical amplification section 112 is controlled by the control circuit 150, and becomes larger, with the result that as the wavelength becomes longer, the gain becomes smaller, generating a gain gradient (Fig. 4 (c)). However, the loss gradient of the variable loss-gradient device 140 is controlled by the control circuit 150 at this time, and the longer the wavelength, the smaller the loss. Consequently, the gain gradient of the input-side optical amplification section 111 and output-side optical amplification section 112 is offset by the loss gradient of the variable loss-gradient device 140, and this results in the gain characteristics of the optical amplifier 100 as a whole becoming approximately constant without being wavelength dependent (Fig. 4 (d)).

[0027] As described above, in this embodiment, even when the input signal light power varies, the output signal light power can be maintained at a predetermined target value, and the gain flatness of the entire

optical amplifier 100 can be maintained. In addition, since the loss of the variable loss-gradient device 140 is almost constant at a predetermined wavelength in the wavelength band of signal light, the noise factor does not degrade. In this embodiment, the variable loss-gradient device 140 may be located on the output side of the output-side optical amplification section 112.

[0028]

(Second Embodiment)

Next, a second embodiment of an optical amplifier and optical amplifier control method related to the present invention will be explained. Fig. 5 is a simplified block diagram of an optical amplifier 200 related to a second embodiment. Fig. 5 also illustrates an optical amplifier 200A provided on the input side of the optical amplifier 200. In the optical amplifier 200 according to this embodiment, an optical coupler 230, input-side optical amplification section 211, variable loss-gradient device 240, and output-side optical amplification section 212 are sequentiallyconnected between an optical input terminal 201 and an optical output terminal 202. The optical amplifier 200 also has an optical pumping light source 221 for supplying optical pumping light to the input-side optical amplification section 211, an optical pumping light source 222 for supplying optical

pumping light to the output-side optical amplification section 212, and a control circuit 250 for controlling the loss spectrum of the variable loss-gradient device 240.

[0029] The optical coupler 230 demultiplexes a portion of the light that arrives from the optical input terminal 201 and outputs it toward the control circuit 250, and outputs the remaining portion [of the light] to the input-side optical amplification section 211. The input-side optical amplification section 211 is supplied with pumping light by the pumping light source 221, and signal light arriving from the optical coupler 230 is collectively amplified and outputted. The variable loss-gradient device 240 has a loss spectrum, wherein the loss in a prescribed wavelength within the wavelength band of the signal light is approximately constant, and the gradient of loss relative to a wavelength in this wavelength band is variable. The output-side optical amplification section 212 is supplied with pumping light by a pumping light source 222, and signal light arriving from the variable loss-gradient device 240 is collectively amplified and outputted to the optical output terminal 202.

[0030] The control circuit 250 detects the power of the inputted signal light demultiplexed by the optical coupler 230, and, in addition, inputs information

related to the output signal light power of an optical amplifier 200A on the input side, which is sent from the optical amplifier 200A on the input side. The control circuit 250 calculates the necessary gain on the basis of the output signal light power of the input-side optical amplifier 200A and the input signal light power of the optical amplifier of its own and controls the powers of optical pumping light to be output from the optical pumping light sources 221 and 222 such that the power of output signal light has a predetermined target value. The control circuit 250 also controls the loss gradient of the variable loss-gradient device 240 on the basis of the necessary gain.

[0031] The constitutions of the input-side optical amplification section 111 and the output-side optical amplification section 112, respectively, are the same as those illustrated in Fig. 2. The constitution of the variable loss-gradient device 240 is the same as that illustrated in Fig. 3. Also, the operation of the optical amplifier 200 and the optical amplifier control method related to this embodiment are approximately the same as those described in Fig. 4. However, in this embodiment, the loss gradient of the variable loss-gradient device 240 is controlled by the control circuit 250, which monitors the required gain. When the necessary gain becomes large, the gain of optical

amplification of signal light by the input-side optical amplification section 211 and output-side optical amplification section 212 becomes smaller as the wavelength becomes long, and the gain gradient is created. At this time, however, the loss gradient of the variable loss-gradient device 240 is controlled by the control circuit 250 so that the longer the wavelength is, the smaller the loss becomes. Hence, the gain gradient of the input-side optical amplification section 211 and output-side optical amplification section 212 is canceled by the loss gradient of the variable loss-gradient device 240. As a result, the gain characteristic of the entire optical amplifier 200 becomes almost constant independently of the wavelength.

[0032] As described above, in this embodiment as well, even when the input signal light power varies, the output signal light power can be maintained at a target value, and the gain flatness of the entire optical amplifier 200 can be maintained. In addition, since the loss of the variable loss-gradient device 240 is almost constant at a predetermined wavelength in the wavelength band of signal light, the noise factor does not degrade. In this embodiment, the variable loss-gradient device 240 may be located on the output side of the output-side optical amplification section 212.

[0033]

(Third Embodiment)

In the optical amplifier 300 according to this embodiment, an optical coupler 331, input-side optical amplification section 311, output-side optical amplification section 312, variable loss-gradient device 340, and optical coupler 332 are sequentially connected between an optical input terminal 301 and an optical output terminal 302. The optical amplifier 300 also has an optical pumping light source 321 for supplying optical pumping light to the input-side optical amplification section and an optical pumping light source 322 for supplying optical pumping light to the output-side optical amplification section 312, and a control circuit 350 for controlling the loss spectrum of the variable loss-gradient device 340.

[0034] The optical coupler 331 demultiplexes a portion of the light that arrives from the optical input terminal 301 and outputs it toward the control circuit 350, and outputs the remaining portion [of the light] to the input-side optical amplification section 311. The input-side optical amplification section 311 is supplied with pumping light by the pumping light source 321, and signal light arriving from the optical coupler 331 is collectively amplified and outputted. The output-side optical amplification section 312 is

supplied with pumping light by a pumping light source 322, and signal light arriving from the input-side optical amplification section 311 is collectively amplified and outputted. The variable loss-gradient device 340 has a loss spectrum, wherein the loss in a prescribed wavelength within the wavelength band of the signal light is approximately constant, the gradient of loss relative to a wavelength in this wavelength band is variable, and signal light arriving from the output-side optical amplification section 312 is applied as loss. The optical coupler 332 demultiplexes a portion of the light that arrives from the variable loss-gradient device 340 and outputs it toward the control circuit 350, and outputs the remaining portion [of the light] to the optical output terminal 302.

[0035] The control circuit 350 detects the power of input signal light demultiplexed by the optical coupler 331 and detects the power of output signal light demultiplexed by the optical coupler 332. The control circuit 350 controls the powers of optical pumping light to be output from the optical pumping light sources 321 and 322 such that the power of output signal light has a predetermined target value. The control circuit 350 calculates the gain on the basis of the output signal light power and input signal light power and controls the loss gradient of the variable

loss-gradient device 340 on the basis of the gain.

[0036] The constitutions of the input-side optical amplification section 311 and the output-side optical amplification section 312, respectively, are the same as those illustrated in Fig. 2. The constitution of the variable loss-gradient device 340 is the same as that illustrated in Fig. 3. Also, the operation of the optical amplifier 300 and the optical amplifier control method related to this embodiment are approximately the same as those described in Fig. 4. However, in this embodiment, the loss gradient of the variable loss-gradient device 340 is controlled by the control circuit 350, which calculates gain. Moreover, when the gain becomes large, the gain of optical amplification of signal light by the input-side optical amplification section 311 and output-side optical amplification section 312 becomes smaller as the wavelength becomes long; the gain gradient is created. At this time, however, the loss gradient of the variable loss-gradient device 340 is controlled by the control circuit 350 so that the longer the wavelength is, the smaller the loss becomes. Hence, the gain gradient of the input-side optical amplification section 311 and output-side optical amplification section 312 is canceled by the loss gradient of the variable loss-gradient device 340. As a result, the gain

characteristic of the entire optical amplifier 300 becomes almost constant independently of the wavelength.

[0037] As described above, in this embodiment as well, even when the input signal light power varies, the output signal light power can be maintained at a target value, and the gain flatness of the entire optical amplifier 300 can be maintained. In addition, since the loss of the variable loss-gradient device 340 is almost constant at a predetermined wavelength in the wavelength band of signal light, the noise factor does not degrade. In this embodiment, the variable loss-gradient device 340 may be located between the input-side optical amplification section 311 and the output-side optical amplification section 312.

[0038]

(Fourth Embodiment)

Next, the fourth embodiment of the optical amplifier and the optical amplifier control method according to the present invention will be described. Fig. 7 is a schematic view showing the arrangement of an optical amplifier 400 according to the fourth embodiment. In the optical amplifier 400 according to this embodiment, an input-side optical amplification section 411, output-side optical amplification section 412, and variable loss-gradient device 440 are sequentially connected between an optical input

terminal 401 and an optical output terminal 402. Moreover, the optical amplifier 400 has optical pumping light sources 421 for supplying optical pumping light to the input-side optical amplification section 411, optical pumping light sources 422 for supplying optical pumping light to the output-side optical amplification section 412, a spectrum monitor device 460 for monitoring the powers of signal light components with respective wavelengths, which are output from the optical output terminal 402, and a control circuit 450 for controlling the loss spectrum of the variable loss-gradient device 440.

[0039] The input-side optical amplification section 411 is supplied with pumping light by the pumping light source 421, and signal light arriving from the optical input terminal 401 is collectively amplified and outputted. The output-side optical amplification section 412 is supplied with pumping light by a pumping light source 422, and signal light arriving from the input-side optical amplification section 411 is collectively amplified and outputted. The variable loss-gradient device 440 has a loss spectrum, wherein the loss in a prescribed wavelength within the wavelength band of the signal light is approximately constant, the gradient of loss relative to a wavelength in this wavelength band is variable, and signal light

arriving from the output-side optical amplification section 412 is applied as loss.

[0040] Part of light output from the optical output terminal 402 is branched and then demultiplexed by the spectrum monitor device 460, or light output from a second sub optical path 22 of the variable loss-gradient device 440 having the structure shown in Fig. 3 is demultiplexed by the spectrum monitor device 460. This spectrum monitor device 460 can be implemented by, e.g., an AWG (Arrayed-Waveguide Grating). In this case, the spectrum monitor device 460 can be formed on a common substrate together with the variable loss-gradient device 440 having the structure shown in Fig. 3, so the downsizing is possible.

[0041] The control circuit 450 controls the power of output signal light component with respective wavelengths, which are demultiplexed by the spectrum monitor device 460. The control circuit 450 controls the powers of optical pumping light to be output from the optical pumping light sources 421 and 422 such that the power of output signal light has a predetermined target value. The control circuit 450 also controls the loss gradient of the variable loss-gradient device 440 on the basis of any deviation between the powers of output signal light components with respective

wavelengths such that the deviation becomes small.

[0042] The constitutions of the input-side optical amplification section 411 and the output-side optical amplification section 412, respectively, are the same as those illustrated in Fig. 2. The constitution of the variable loss-gradient device 440 is the same as that illustrated in Fig. 3. Also, the operation of the optical amplifier 400 and the optical amplifier control method related to this embodiment are approximately the same as those described in Fig. 4. However, in this embodiment, the loss gradient of the variable loss-gradient device 440 is controlled by the control circuit 350 on the basis of the power deviation of the outputted signal light of each wavelength demultiplexed by a spectrum monitor device 460.

[0043] Next, preferred examples of the variable loss-gradient device 440 and spectrum monitor device 460 will be described. Fig. 8 is an explanatory view of the variable loss-gradient device 440 and spectrum monitor device 460. The variable loss-gradient device 440 and spectrum monitor device 460 are formed on a common substrate 10A. The variable loss-gradient device 440 has the same structure as that shown in Fig. 3. The spectrum monitor device 460 is formed from an AWG formed on the substrate 10A. More specifically, the spectrum monitor device 460 has an input-side slab

waveguide 61, array waveguide section 62 having a plurality of channel waveguides, output-side slab waveguide 63, and output-side channel waveguides 64_1 to 64_N.

[0044] Light output from the second sub optical path 22 of the variable loss-gradient device 440 is input to the input-side slab waveguide 61. The light is output to the channel waveguides of the array waveguide section 62. The plurality of channel waveguides of the array waveguide section 62 have different optical path lengths from the input-side slab waveguide 61 to the output-side slab waveguide 63 and give different phases to the light to be guided. The output-side slab waveguide 63 receives light from each of the plurality of channel waveguides of the array waveguide section 62 and outputs the light to each of the output-side channel waveguides 64_1 to 64_N.

[0045] The light components output to the output-side channel waveguides 64_1 to 64_N are signal light components having respective wavelengths, which are obtained by demultiplexing the light output from the second sub optical path 22 of the variable loss-gradient device 440. The control circuit 450 detects the powers of signal light components having respective wavelengths, which are output to the output-side channel waveguides 64_1 to 64_N of the spectrum monitor

device 460, and controls the loss gradient of the variable loss-gradient device 440 such that the deviation between the powers of signal light components having respective wavelengths becomes small. The control circuit 450 may control the loss gradient of the variable loss-gradient device 440 such that the deviation between powers of two signal light components having respective wavelengths (e.g., the maximum wavelength and minimum wavelength) in the signal light components having respective wavelengths, which are demultiplexed by the spectrum monitor device 460.

[0046] As described above, in this embodiment as well, even when the input signal light power varies, the output signal light power can be maintained at a predetermined target value, and the gain flatness of the entire optical amplifier 400 can be maintained. In addition, since the loss of the variable loss-gradient device 440 is almost constant at a predetermined wavelength in the wavelength band of signal light, the noise factor does not degrade. Furthermore, in this embodiment, since the loss gradient of the variable loss-gradient device 440 is feedback-controlled, stable operation is possible.

[0047]

(Fifth Embodiment)

Next, the fifth embodiment of the optical

amplifier and the optical amplifier control method according to the present invention will be described. Fig. 9 is a schematic view showing the arrangement of an optical amplifier 500 according to the fifth embodiment. In the optical amplifier 500 according to this embodiment, a gain equalizer 170 is inserted between an input-side optical amplification section 111 and a variable loss-gradient device140 of the optical amplifier 100 according to the first embodiment. The gain equalizer 170 equalizes gain wavelength dependence unique to the input-side optical amplification section 111 and output-side optical amplification section 112. This gain equalizer 170 can be implemented by, e.g., an optical fiber grating element having index modulation in the core of an optical fiber or an etalon filter having a Fabry-Perot resonator structure.

[0048] The operation of the optical amplifier 500 according to the fifth embodiment, and an optical amplifier control method according to the fifth embodiment will be described next. Fig.10 is a view for explaining the operation of the optical amplifier 500 according to the fifth embodiment. Even when the input signal light power has a predetermined value, the gain spectrum of the input-side optical amplification section 111 and output-side optical amplification section 112 is not strictly constant and has a gain

wavelength dependence unique to the input-side optical amplification section 111 and output-side optical amplification section 112 (Fig. 10(a)). The gain equalizer 170 has a loss spectrum having the same shape as that of the gain spectrum of the input-side optical amplification section 111 and output-side optical amplification section 112 at this time. .

[0049] When the input signal light power has a value smaller than the predetermined value, the gain of optical amplification of signal light by the input-side optical amplification section 111 and output-side optical amplification section 112 is controlled by a control circuit 150 and becomes large. Consequently, the longer the wavelength becomes, the smaller the gain becomes, so the gain gradient is created and moreover the inherent wavelength-dependent gain is superimposed on the gain gradient (Fig. 10 (b)). At this time, however, the loss gradient of the variable loss-gradient device 140 is controlled by the control circuit 150 such that the longer the wavelength is, the smaller the gain becomes.

[0050] The above-mentioned inherent wavelength-dependency of the gain, which is superimposed on the gain gradient of the input-side optical amplification section 111 and the output-side optical amplification section 112, is equalized by a gain equalizer 170 (Fig.

10 (c)). Then, the gain gradient of the input-side optical amplification section 111 and the output-side optical amplification section 112 is offset by the loss gradient of the variable loss-gradient device 140. As a result, the gain characteristics of the optical amplifier 500 as a whole are not dependent on wavelength and become approximately constant.

[0051] As described above, in this embodiment as well, even when the input signal light power varies, the output signal light power can be maintained at a predetermined target value, and the gain flatness of the entire optical amplifier 500 can be maintained. Especially in this embodiment, since the gain equalizer 170 is provided in addition to the variable loss-gradient device 140, the gain flatness of the entire optical amplifier 500 is excellent. In addition, since the loss of the variable loss-gradient device 140 is almost constant at a predetermined wavelength in the wavelength band of signal light, the noise factor does not degrade. In this embodiment, one or both of the variable loss-gradient device 140 and gain equalizer 170 may be located on the output side of the output-side optical amplification section 112.

[0052] The present invention is not limited to the above embodiments, and various changes and modifications can be made. For example, the

fluorescent material to doped into the amplification optical fiber is not limited to Er, and another rare earth element (e.g., Tm, Pr, Nd, or the like) may be used. Instead of the amplification optical fiber, a planar optical waveguide doped with a fluorescent material that can be excited by optical pumping light may be used. The optical amplifier need not always be divided into the input-side optical amplification section and output-side optical amplification section. Moreover, a gain equalizer may be inserted in any one of the optical amplifiers according to the second to fourth embodiments. Further, a gain equalizer can be inserted into any of the optical amplifiers related to the first through the fourth embodiments.

[0053]

[Effects of the Invention]

As explained in detail hereinabove, according to the present invention, the signal light power outputted from the amplifier can be maintained at a constant target value even when the signal light power inputted to the optical amplifier fluctuates. Further, the gain flatness of the optical amplifier as a whole can be maintained by adjusting the gradient of loss of the variable loss-gradient device even when a gradient of gain of the optical amplification section is generated by the fluctuation of input signal light power. In

addition, since the loss of the variable loss-gradient device is approximately constant in a prescribed wavelength within the wavelength band of the signal light, the noise factor does not deteriorate.

[0054] Further, when a gain equalizer is used to equalize the wavelength-dependency of the gain inherent in the optical amplification section, the gain gradient of the optical amplification section is compensated by the variable loss-gradient device and the inherent wavelength-dependency of the gain of the optical amplification section is equalized, resulting in excellent gain flatness for the optical amplifier as a whole.

[0055] Further, the gradient of loss of the variable loss-gradient device can either be controlled on the basis of the power inputted to the optical amplification section; or can be controlled on the basis of the optical amplification gain in the optical amplification section; or can be controlled on the basis of the power deviation of respective wavelengths outputted from the optical amplification section. Any of these cases is ideal from the standpoint of using the variable loss-gradient device to compensate the gain gradient of the optical amplification section, and to maintain the gain flatness of the optical amplifier as a whole. In particular, stable operation is made

possible when feedback control is applied to the loss gradient of the variable loss-gradient device on the basis of the output power deviation of the respective wavelengths.

[0056] Further, it is preferable that the variable loss-gradient device be constituted such that a first and second Mach-Zehnder interferometer are cascaded, and that control of the gradient of loss be performed via temperature control. This variable loss-gradient device can be made smaller via integration on a substrate, and insertion loss will be small. Furthermore, this variable loss-gradient device can also be integrated on a substrate together with a spectrum monitor device.

[0057] Further, noise factor deterioration is lessened when a variable loss-gradient device is disposed on the output side of the optical amplification section, and when the optical amplification section is divided into a plurality of stages, and a variable loss-gradient device is disposed between [one] stage and [another] stage of the optical amplification section.

[Brief Explanation of the Drawings]

Fig. 1 is a simplified block diagram of an optical amplifier related to a first embodiment;

Fig. 2 is a schematic diagram of an input-side optical amplification section and a pumping light

source;

Fig. 3 is a schematic diagram of a variable loss-gradient device;

Fig. 4 is a diagram illustrating the operation of an optical amplifier related to the first embodiment;

Fig. 5 is a simplified block diagram of an optical amplifier related to a second embodiment;

Fig. 6 is a simplified block diagram of an optical amplifier related to a third embodiment;

Fig. 7 is a simplified block diagram of an optical amplifier related to a fourth embodiment;

Fig. 8 is a schematic diagram of a variable loss-gradient device and spectrum monitor device;

Fig. 9 is a simplified block diagram of an optical amplifier related to a fifth embodiment; and

Fig. 10 is a diagram illustrating the operation of an optical amplifier related to the fifth embodiment.

[Explanation of Reference Numerals]

100...OPTICAL AMPLIFIER, 111...INPUT-SIDE OPTICAL AMPLIFICATION SECTION, 112...OUTPUT-SIDE OPTICAL AMPLIFICATION SECTION, 113...OPTICAL FIBER FOR AMPLIFICATION, 114...OPTICAL COUPLER, 115,116...OPTICAL ISOLATOR, 121,122...PUMPING LIGHT SOURCE, 130...OPTICAL COUPLER, 140...VARIABLE LOSS-GRADIENT DEVICE, 150...CONTROL CIRCUIT, 170...GAIN EQUALIZER, 200...OPTICAL AMPLIFIER, 211...INPUT-SIDE OPTICAL

AMPLIFICATION SECTION, 212...OUTPUT-SIDE OPTICAL AMPLIFICATION SECTION, 221,222...PUMPING LIGHT SOURCE, 230...OPTICAL COUPLER, 240...VARIABLE LOSS-GRADIENT DEVICE, 250...CONTROL CIRCUIT, 300...OPTICAL AMPLIFIER, 311...INPUT-SIDE OPTICAL AMPLIFICATION SECTION, 312...OUTPUT-SIDE OPTICAL AMPLIFICATION SECTION, 321,322...PUMPING LIGHT SOURCE, 331,332...OPTICAL COUPLER, 340...VARIABLE LOSS-GRADIENT DEVICE, 350...CONTROL CIRCUIT, 400...OPTICAL AMPLIFIER, 411...INPUT-SIDE OPTICAL AMPLIFICATION SECTION, 412...OUTPUT-SIDE OPTICAL AMPLIFICATION SECTION, 421,422...PUMPING LIGHT SOURCE, 440...VARIABLE LOSS-GRADIENT DEVICE, 450...CONTROL CIRCUIT, 460...SPECTRUM MONITOR DEVICE, 500...OPTICAL AMPLIFIER.

[Document Title] Abstract

[Abstract]

[Problem] To provide an optical amplifier and so forth capable of maintaining output signal light power and gain flatness without degrading the noise factor even when input signal light power fluctuates.

[Solution] A variable loss-gradient device 140 has a loss spectrum, wherein the loss in a prescribed wavelength within the wavelength band of the signal light is approximately constant, and the gradient of loss relative to a wavelength in this wavelength band is variable. A control circuit 150 detects the power of a signal light demultiplexed by an optical coupler 130, and, based on the input signal light power thereof, controls the power of a pumping light supplied to optical amplification sections 111, 112 from pumping light sources 121, 122 such that the power of the output signal light constitutes a constant target value. Further, control circuit 150 controls the loss gradient of the variable loss-gradient device 140 on the basis of the input signal light power thereof.

[Selected Drawing] Fig. 1

FIG. 1

100: OPTICAL AMPLIFIER

121: PUMPING LIGHT SOURCE

122: PUMPING LIGHT SOURCE

140: VARIABLE LOSS-GRADIENT DEVICE

150: CONTROL CIRCUIT

FIG. 2

121: PUMPING LIGHT SOURCE

FIG. 4

(a) LOSS

WAVELENGTH

GAIN DECREASED

GAIN INCREASED

(b) GAIN

WAVELENGTH

GAIN INCREASED

(c) GAIN

WAVELENGTH

(d) GAIN

WAVELENGTH

FIG. 5

200: OPTICAL AMPLIFIER

200A: OPTICAL AMPLIFIER

221: PUMPING LIGHT SOURCE

222: PUMPING LIGHT SOURCE

240: VARIBABLE LOSS-GRADIENT DEVICE

250: CONTROL CIRCUIT

FIG. 6

300: OPTICAL AMPLIFIER

321: PUMPING LIGHT SOURCE

322: PUMPING LIGHT SOURCE

340: VARIABLE LOSS-GRADIENT DEVICE

350: CONTROL CIRCUIT

FIG. 7

400: OPTICAL AMPLIFIER

421: PUMPING LIGHT SOURCE

422: PUMPING LIGHT SOURCE

440: VARIABLE LOSS-GRADIENT DEVICE

450: CONTROL CIRCUIT

460: SPECTRUM MONITOR DEVICE

FIG. 9

121: PUMPING LIGHT SOURCE

122: PUMPING LIGHT SOURCE

140: VARIABLE LOSS-GRADIENT DEVICE

150: CONTROL CIRCUIT

170: GAIN EQUALIZER

FIG. 10

(a) GAIN

WAVELENGTH

(b) GAIN

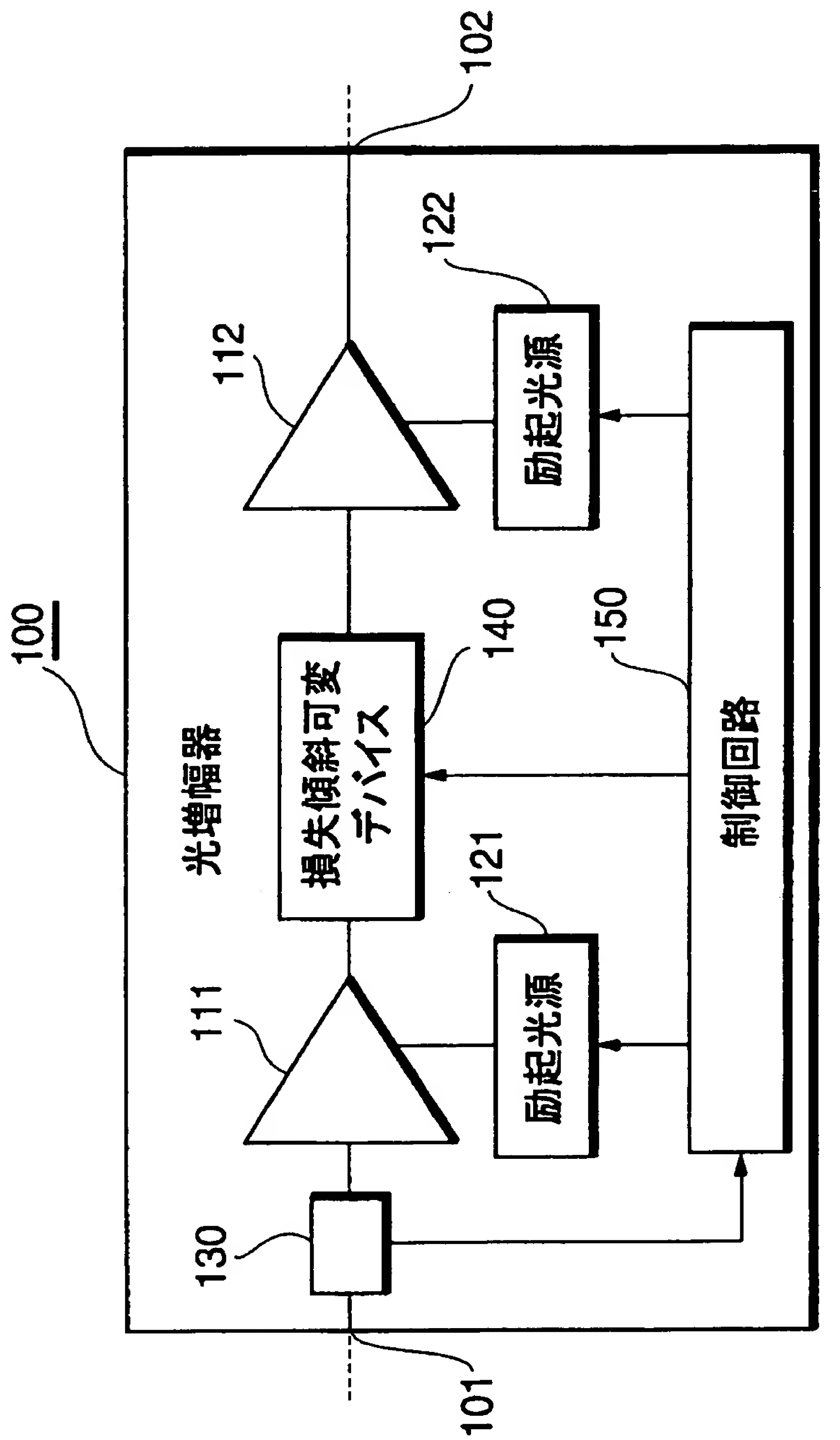
WAVELENGTH

(c) GAIN

WAVELENGTH

【書類名】　図面

【図１】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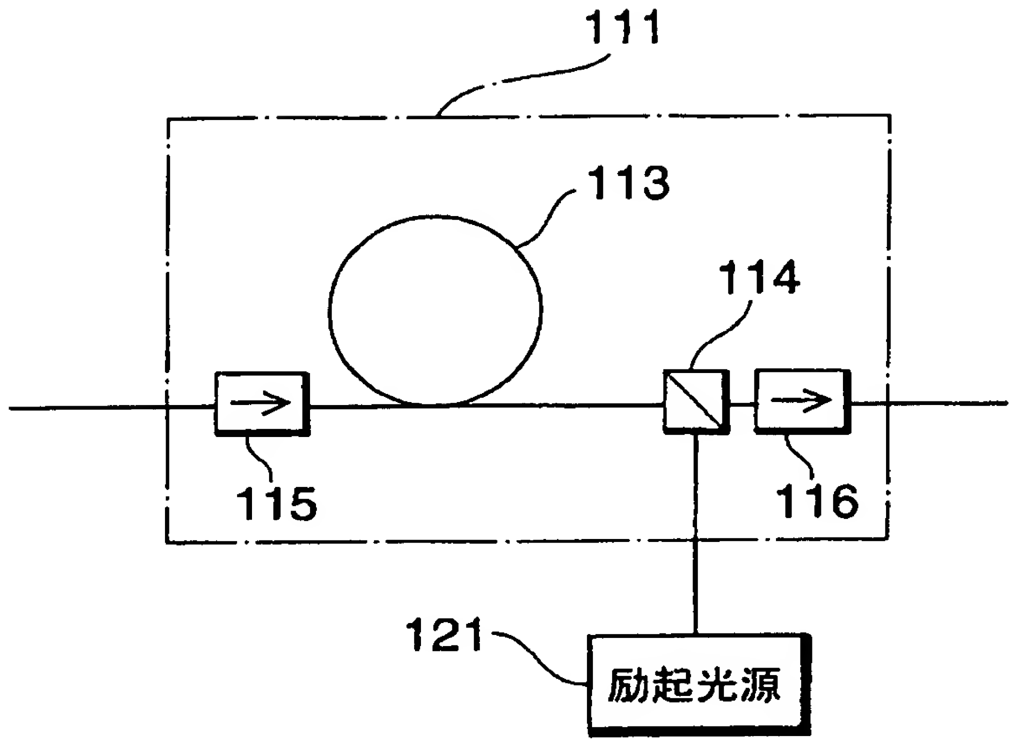

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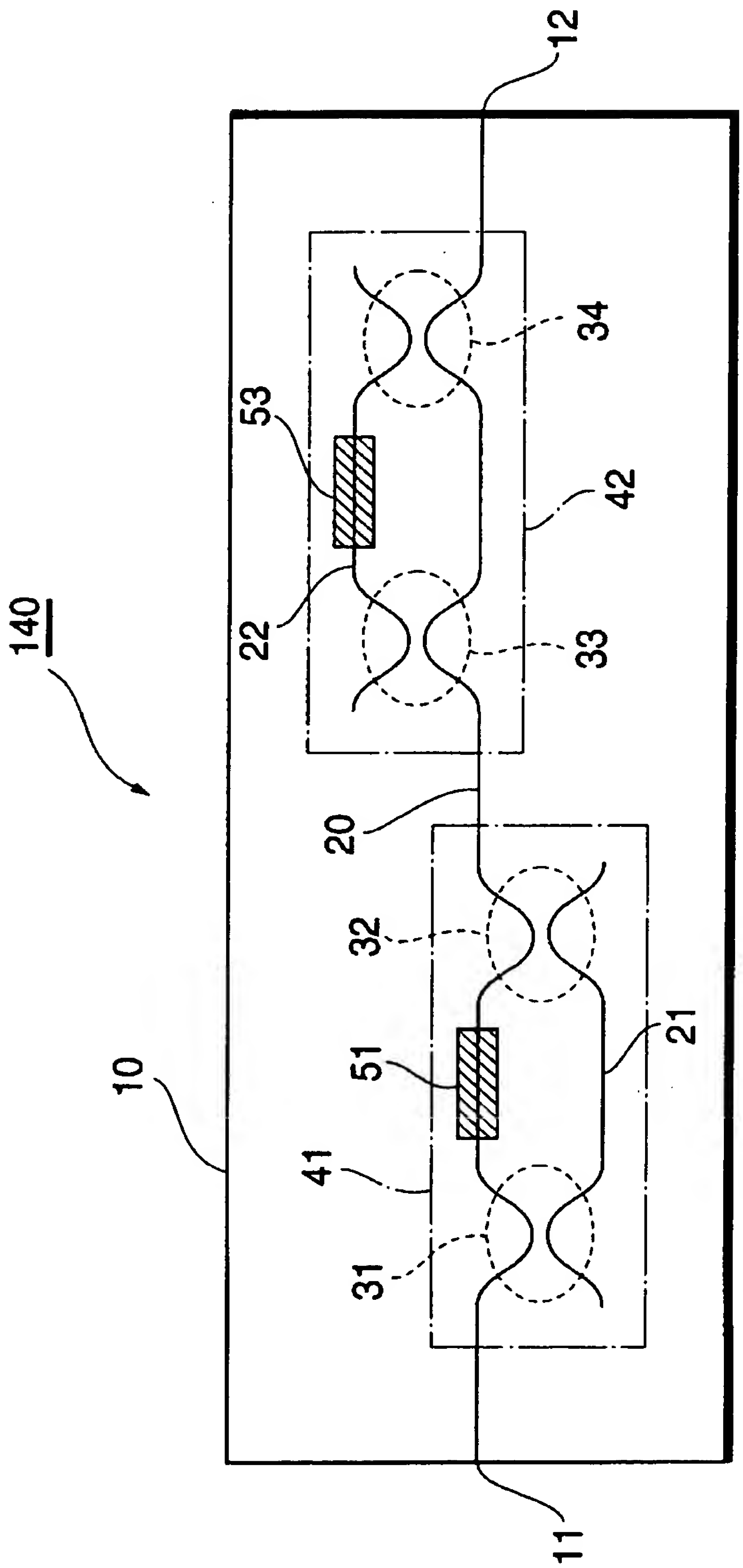

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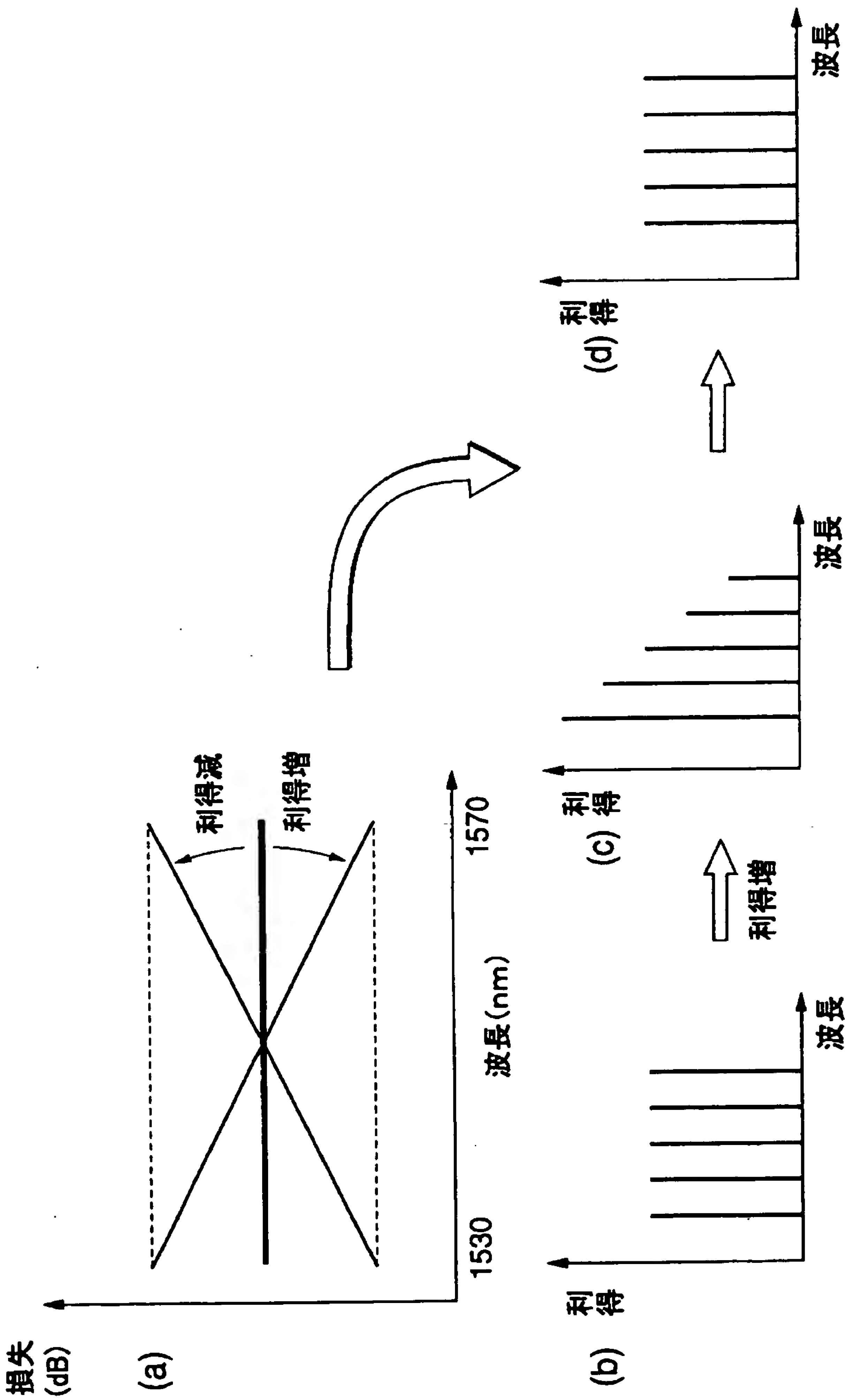

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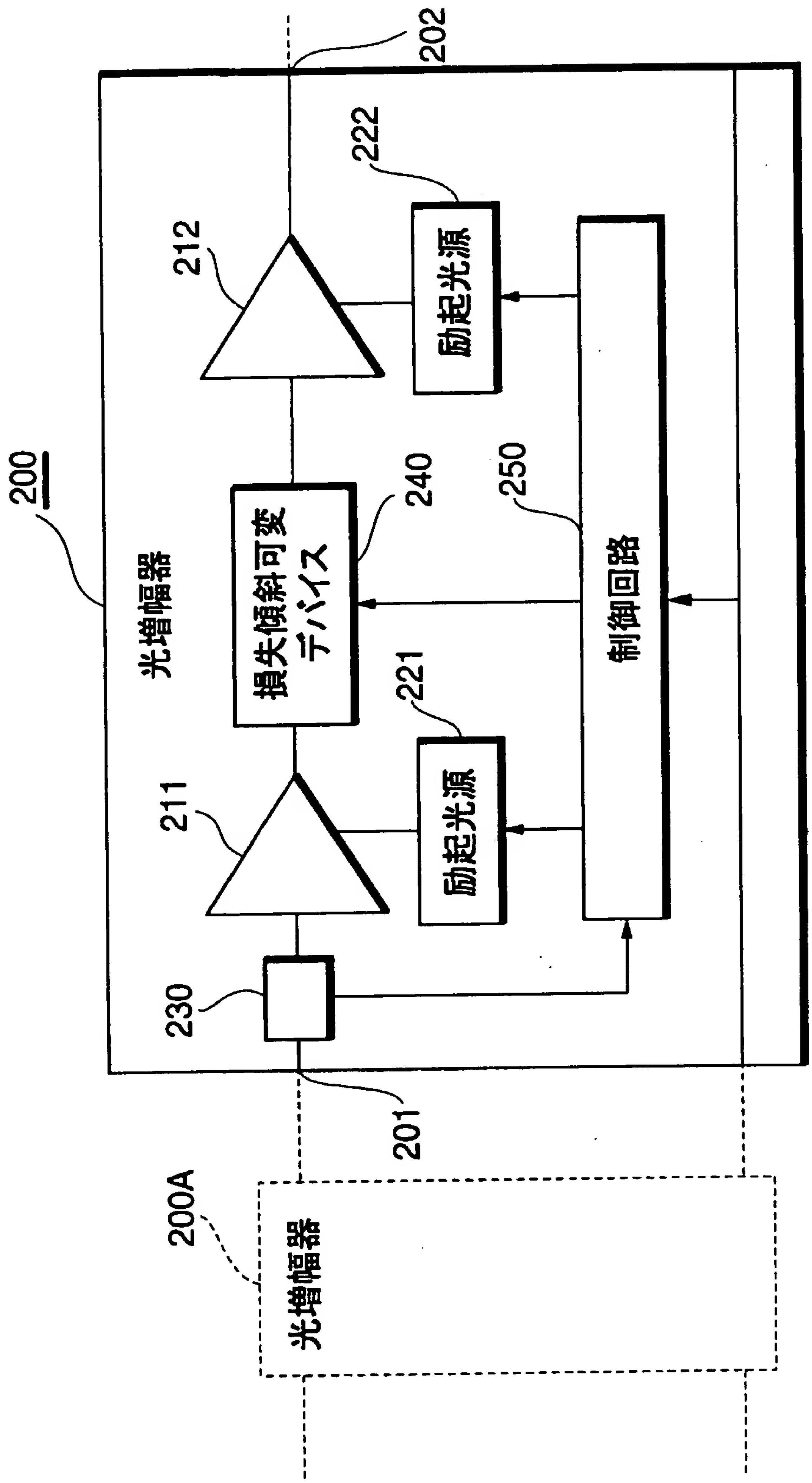
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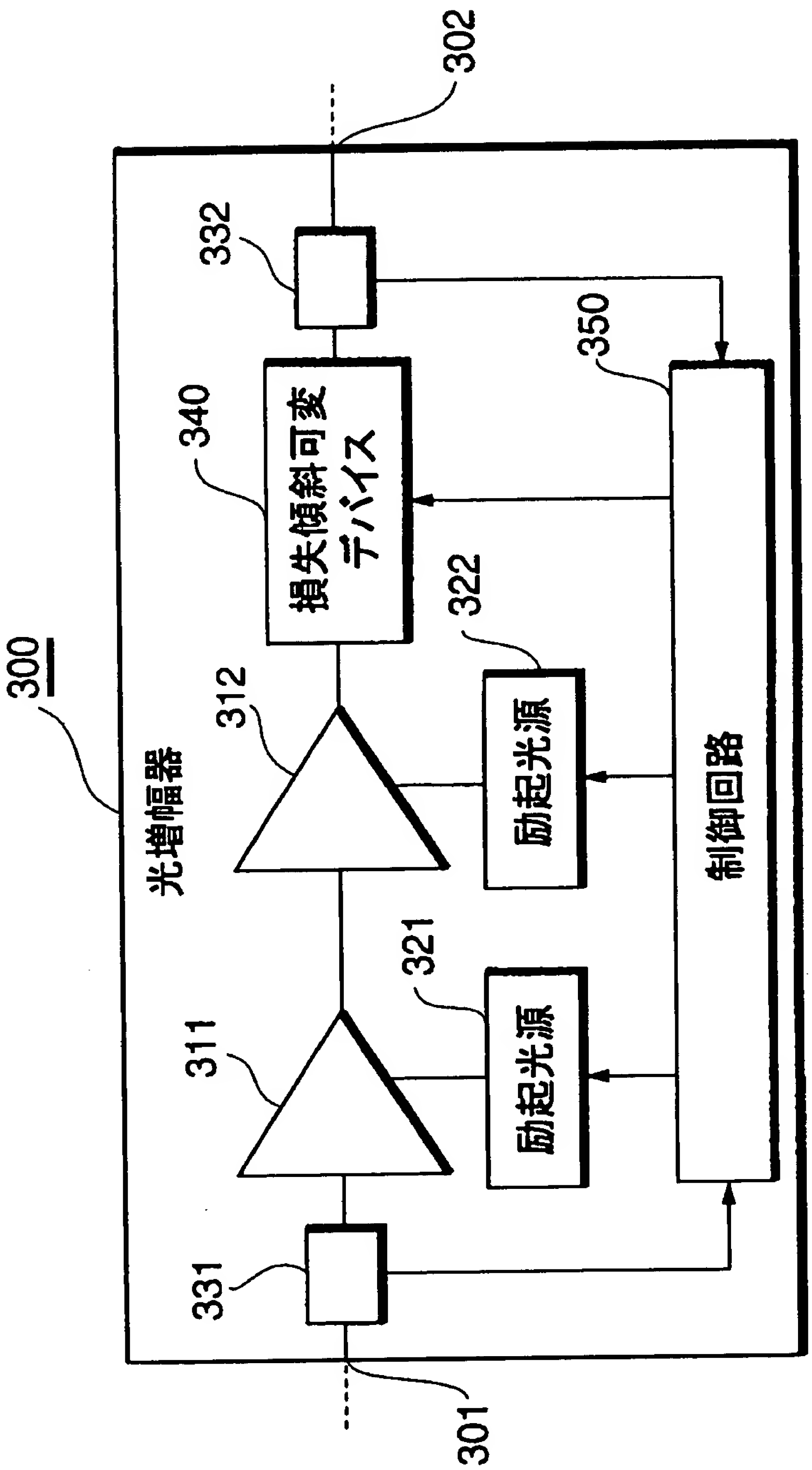
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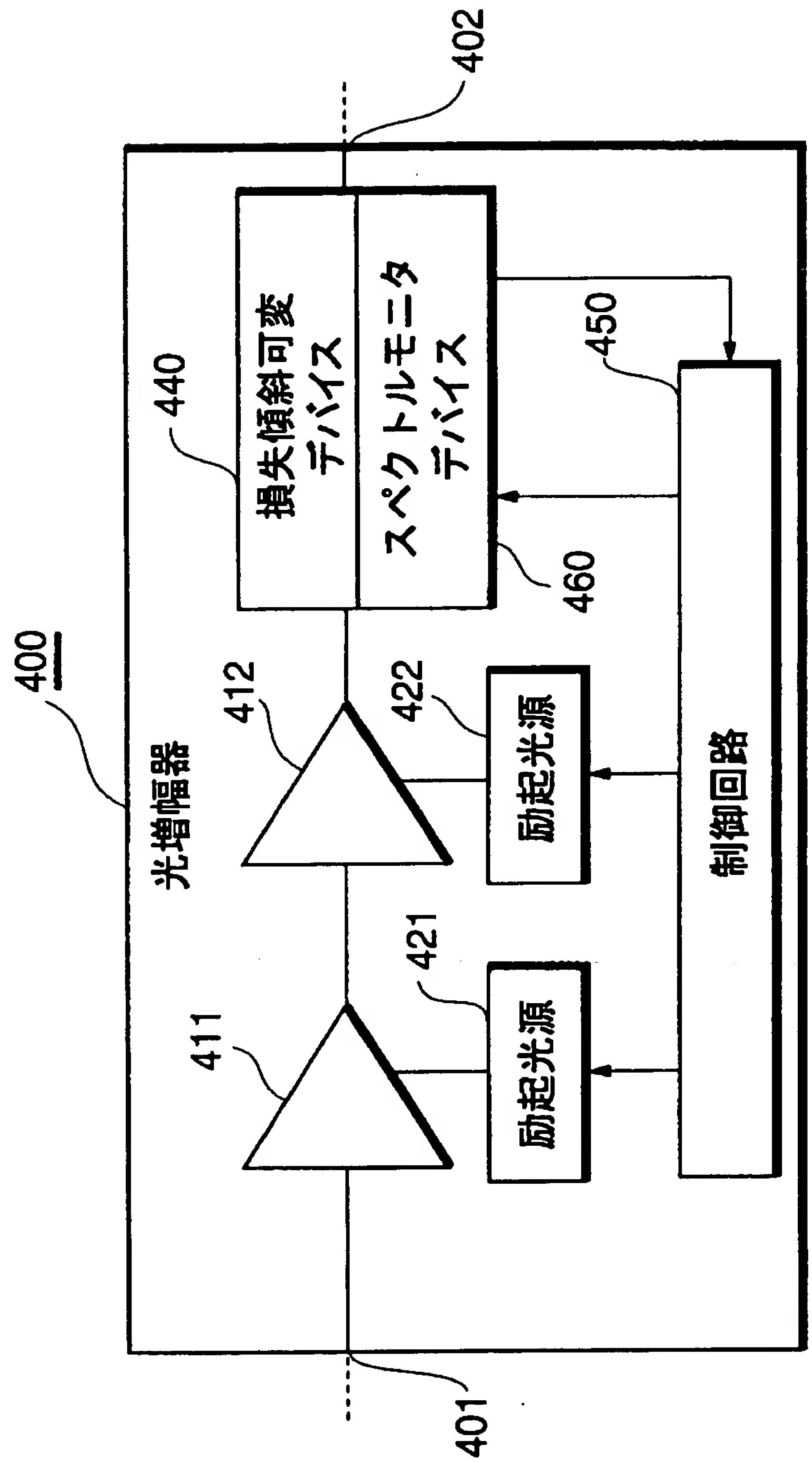
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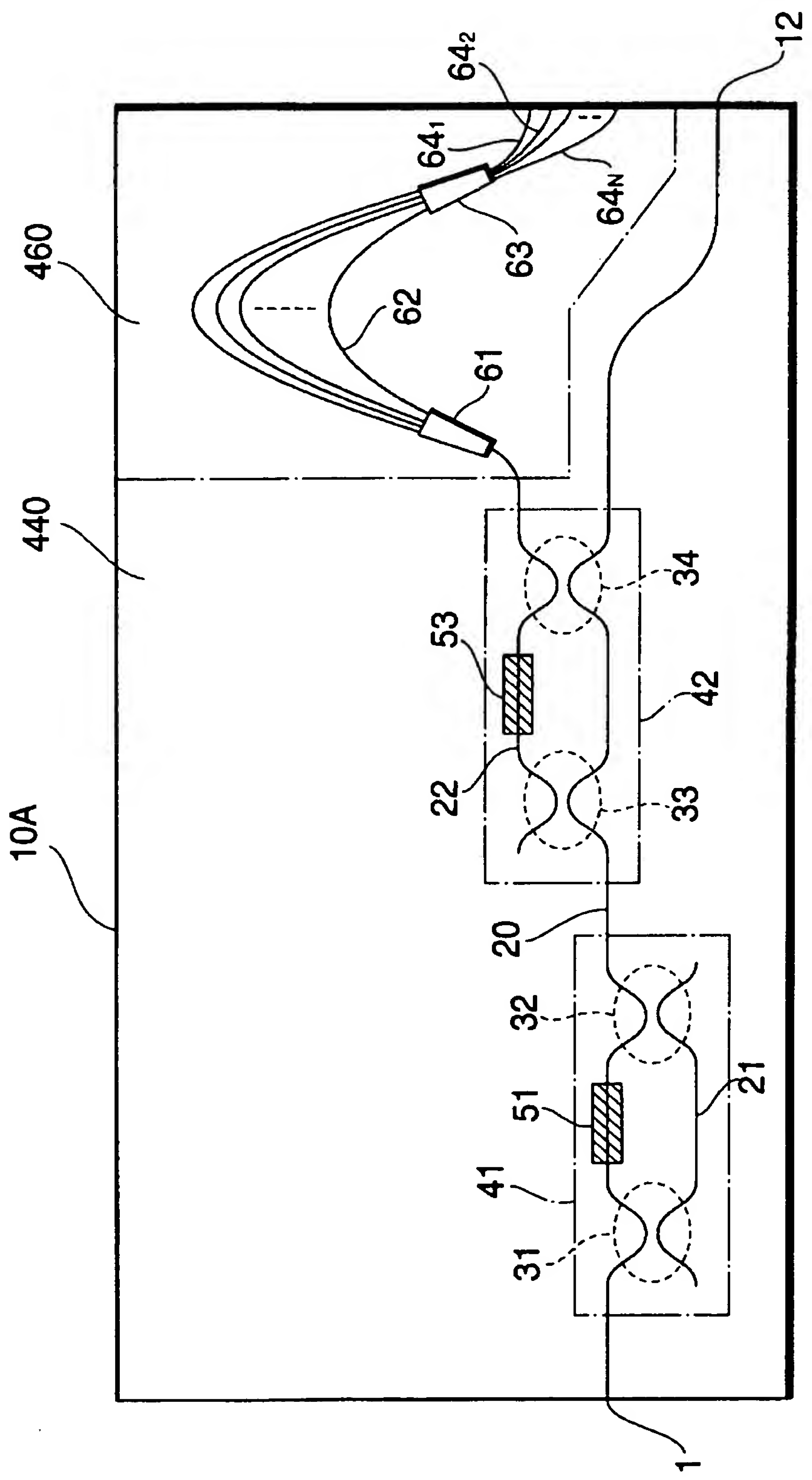
【図８】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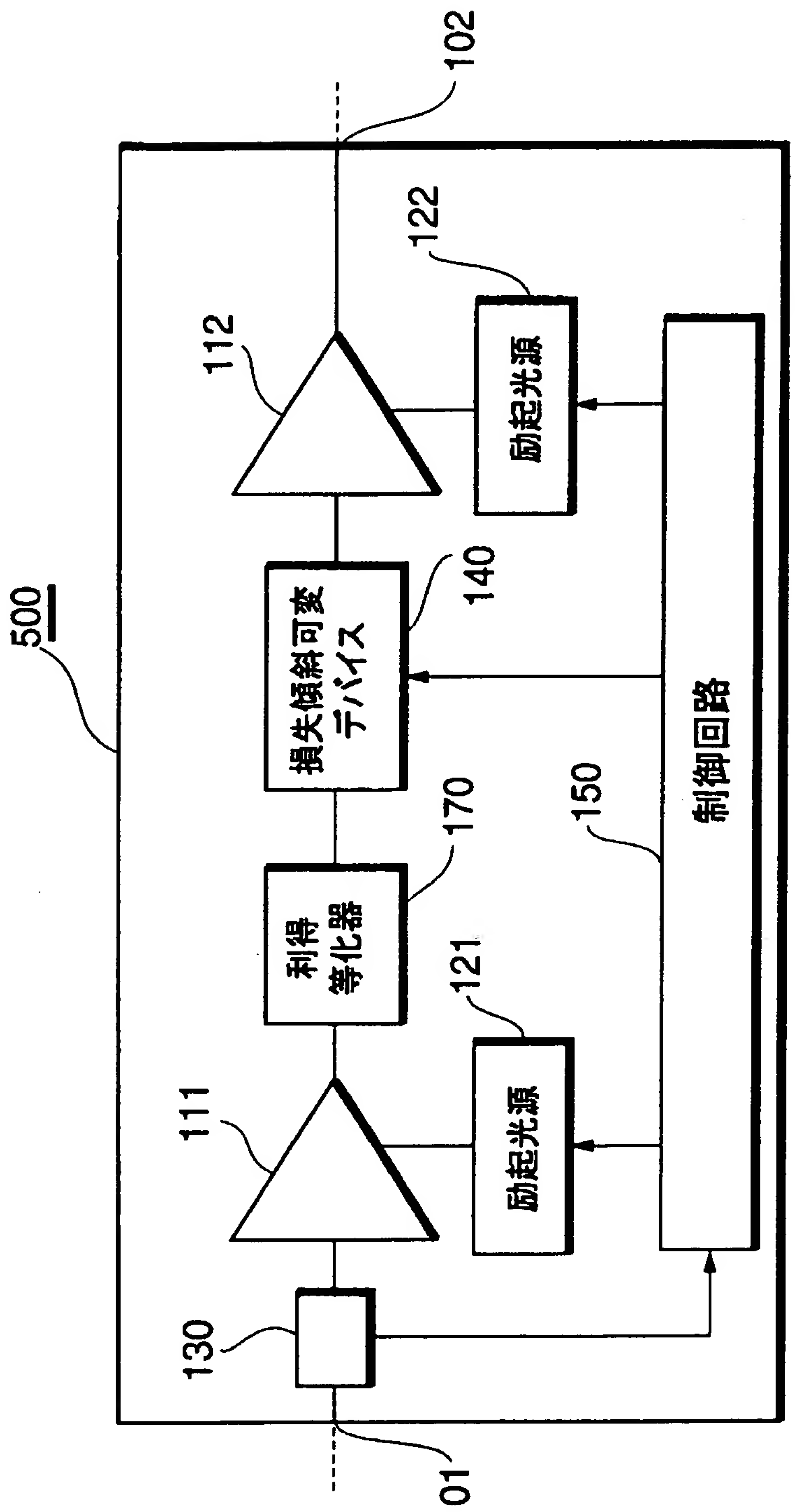
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130
101

【図１０】